Specification

Title of the Invention

[0001]   Objective Lens For Optical Recording/Reproducing
Device

Background of the Invention

[0002]   The present invention relates to an objective
lens used for an optical recording/reproducing device that
is capable of recording/reproducing large amounts of
optical information to/from hologram recording medium.

[0003]   Recently, such optical recording/reproducing
devices using hologram recording medium are in practical
use. Features of the optical recording/reproducing device
using hologram recording medium are: the device can employ
an optical pick-up widely used for optical disc apparatuses
which use optical discs such as a CD, a CD-R and a DVD; the
device can employ a servo mechanism widely used for the
optical disc apparatuses; and the device uses the hologram
recording medium. Hereafter, a hologram recording medium
having a form of a disc or a card is referred to as a
hologram disc.

[0004]   The objective lens mounted on the optical pick-up

provided in the optical recording/reproducing device using the hologram disc is required to be sufficiently corrected for wavefront aberration for a beam from a light source and for a beam reflected from the hologram disc.

[0005]   A fourier transform lens is known as a lens which is sufficiently corrected for wavefront aberration for a beam entering from a incident surface thereof (a light source side surface) and for a beam entering from an exit surface thereof (a recording media side surface).

[0006]   Japanese Provisional Publication No. HEI11-133297 discloses a fourier transform lens having a plurality of lenses. Since the fourier transform lens disclosed in the above mentioned publication has the plurality of lenses, if the fourier transform lens is attached to the optical pick-up employed by the optical disc apparatus, the following problems arise.

[0007]   Firstly, since the fourier transform lens has the plurality of lenses, position adjustments of the plurality of lenses are required. This is troublesome for a worker. Secondly, additional design of a lens frame for holding of the fourier transform lens is required because the fourier transform lens can not be attached to a lens frame mounted on an actuator of the optical pick-up employed by the optical disc apparatus. Use of a new lens frame suitable for the fourier transform lens having the plurality of

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lenses increases a size of the optical recording/reproducing device.

[0008]   Accordingly, the objective lens for the optical recording/reproducing device for the hologram disc is required to be a single lens as in the case of the optical disc apparatus.

Summary of the Invention

[0009]   The present invention is advantageous in that it provides an objective lens suitable for an optical recording/reproducing device for the hologram disc.

[0010]   According to an aspect of the present invention, there is provided an objective lens for an optical recording/reproducing device which records/reproduces information to/from a recording medium utilizing holography. The objective lens converges a collimated beam in the vicinity of a recording surface of the recording medium to record/reproduce the information. The objective lens has a single lens element having an incident surface to which the collimated beam enters and an exit surface being opposite to said incident surface. Further, the incident surface and the exit surface are configured to be rotationally symmetrical aspherical surfaces. At least within an effective diameter of the single lens element, the incident

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surface and the exit surface are symmetrical with respect to a plane perpendicular to an optical axis of the single lens element and have the same shape. The single lens element has positive refractive power.

[0011]   With this configuration, although the objective lens is configured as a single lens, the objective lens has sufficiently corrected aberrations and has high performance as the fourier transform lens. Accordingly, the objective lens which is suitable for recording/reproducing information to/from the hologram disc is provided.

[0012]   Further, since the objective lens is a single lens element, installation of the objective lens on the optical recording/reproducing device is easy. Further, sufficient working distance WD between the objective lens and a cover layer of the recording medium such as the hologram disc can be attained. Since each of an object point and an image point are sufficiently away from the objective lens, objects and images with respect to the objective lens can be positioned with a high degree of flexibility in the optical recording/reproducing device.

[0013]   Optionally, the rotationally symmetrical aspherical surface of each of the two refractive surfaces may be expressed by a formula (1) below:

$$F(h) = \frac{h^2/r}{1 + \sqrt{1 - (1+K)(1/r)^2 h^2}} + A_4 h^4 + A_6 h^6 + A_8 h^8 + A_{10} h^{10} \quad \cdots (1)$$

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where F(h) is a sag amount (i.e., a distance from a plane,
which is tangential to the rotationally symmetrical
aspherical surface at the optical axis, to the rotationally
symmetrical aspherical surface at a position whose height
with respect to the optical axis is h), r is a radius of
curvature of the rotationally symmetrical aspherical
surface at the optical axis , K is a conical coefficient,
and A_4-A_{10} are fourth, sixth, eighth, and tenth order
aspherical coefficients, respectively. In this case, a
first derivative of the sag amount F(h) with respect to h
may satisfy a condition (2) and a second derivative of the
sag amount F(h) with respect to h may satisfy a condition
(3):

$$-0.35 \leq dF(h)/dh \leq +0.35 \qquad \cdots (2)$$

$$+0.3 \ \leq d^2F(h)/d^2h \leq +1.3 \qquad \cdots (3).$$

[0014]   If the conditions (2) and (3) are satisfied,
spherical aberration and a coma (i.e., a sine condition)
are effectively reduced. Therefore, an RMS value of
wavefront aberration can be reduced lower than or equal to
Marechal criterion (0.07 λrms).

[0015]   Still optionally, the objective lens may satisfy
a condition (4):

$$0.9 \leq r/tc \leq 1.5 \qquad \cdots (4)$$

where r represents the radius of curvature on the
optical axis, and tc represents a central lens thickness of

the objective lens.

[0016]   By satisfying the condition (4), astigmatism of the objective lens can be sufficiently reduced. Further, the above mentioned high optical performance which is required for the fourier transform lens can be maintained within the whole range of a required field angle.

[0017]   In a particular case, an image height y of an image formed by the objective lens may be defined by the following equation (5):

$$y = f\sin W \qquad \cdots (5)$$

where f represents a focal length of the objective lens and W represents a field angle. In this case, with regard to each of a beam entering from the incident surface and a beam entering from the exit surface, an entrance pupil plane coincides with a front focal point and an image point coincides with a back focal point.

[0018]   In a particular case, with regard to each of a beam entering from the incident surface and a beam entering from the exit surface, the objective lens may have wavefront aberration performance less than or equal to Marechal criterion within a maximum field angle range.

[0019]   Optionally, half of the maximum field angle may be larger than or equal to 3°.

Brief Description of the Accompanying Drawings

[0020]   Fig. 1 shows an objective optical system having an objective lens according to an embodiment of the invention;

[0021]   Fig. 2 is a graph illustrating values of conditions (2) and (3) of an objective lens of a first example of the embodiment;

[0022]   Fig. 3 is a graph showing spherical aberration and a sine condition of the objective lens of the first example with regard to a beam entering from an incident surface;

[0023]   Fig. 4 is a graph showing astigmatism of the objective lens of the first example with regard to the beam entering from the incident surface;

[0024]   Figs. 5A-5D are graphs showing transverse aberrations of the objective lens of the first example with regard to the beam entering from the incident surface;

[0025]   Figs. 6A-6D are graphs showing the wavefront aberrations of the objective lens of the first example with regard to the beam entering from the incident surface;

[0026]   Fig. 7 is a graph showing a relationship between an RMS value of wavefront aberration and a field angle of the first example with regard to the beam entering from the incident surface;

[0027]   Fig. 8 is a graph showing the spherical

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aberration and the sine condition of the objective lens of the first example with regard to a beam entering from an exit surface;

[0028]   Fig. 9 is a graph showing astigmatism of the objective lens of the first example with regard to the beam entering from the exit surface;

[0029]   Figs. 10A-10D are graphs showing transverse aberrations of the objective lens of the first example with regard to the beam entering from the exit surface;

[0030]   Figs. 11A-11D are graphs showing the wavefront aberrations of the objective lens of the first example with regard to the beam entering from the exit surface;

[0031]   Fig. 12 is a graph showing a relationship between an RMS value of the wavefront aberration and the field angle of the first example with regard to the beam entering from the exit surface;

[0032]   Fig. 13 is a graph showing a fsinW characteristic of the objective lens of the first example;

[0033]   Fig. 14 is a graph illustrating values of the condition (2) and (3) of a second example according to the embodiment;

[0034]   Fig. 15 is a graph showing the spherical aberration and the sine condition of the objective lens of the second example with regard to the beam entering from the incident surface;

[0035]   Fig. 16 is a graph showing astigmatism of the objective lens of the second example with regard to the beam entering from the incident surface;

[0036]   Figs. 17A-17D are graphs showing transverse aberrations of the objective lens of the second embodiment with regard to the beam entering from the incident surface;

[0037]   Figs. 18A-18D are graphs showing the wavefront aberrations of the objective lens of the second example with regard to the beam entering from the incident surface;

[0038]   Fig. 19 is a graph showing a relationship between an RMS value of the wavefront aberration and the field angle of the second example with regard to the beam entering from the incident surface;

[0039]   Fig. 20 is a graph showing the spherical aberration and the sine condition of the objective lens of the second example with regard to the beam entering from the exit surface;

[0040]   Fig. 21 is a graph showing astigmatism of the objective lens of the second example with regard to the beam entering from the exit surface;

[0041]   Figs. 22A-22D are graphs showing transverse aberrations of the objective lens of the second example with regard to the beam entering from the exit surface;

[0042]   Figs. 23A-23D are graphs showing the wavefront aberrations of the objective lens of the second example

with regard to the beam entering from the exit surface;

[0043]   Fig. 24 is a graph showing a relationship between an RMS value of the wavefront aberration and the field angle of the second example with regard to the beam entering from the exit surface;

[0044]   Fig. 25 is a graph showing the fsinW characteristic of the objective lens of the second example;

[0045]   Fig. 26 shows a lens arrangement of an objective lens system according to a third example of the embodiment;

[0046]   Fig. 27 is a graph illustrating values of the conditions (2) and (3) of the third example;

[0047]   Fig. 28 is a graph showing the spherical aberration and the sine condition of the objective lens of the third example;

[0048]   Fig. 29 is a graph showing astigmatism of the objective lens of the third example;

[0049]   Figs. 30A-30D are graphs showing transverse aberrations of the objective lens of the third example;

[0050]   Figs. 31A-31D are graphs showing the wavefront aberrations of the objective lens of the third example;

[0051]   Fig. 32 is a graph showing a relationship between an RMS value of the wavefront aberration and the field angle of the third example;

[0052]   Fig. 33 is a graph showing the fsinW characteristic of the objective lens of the third example;

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[0053]   Fig. 34 shows a lens arrangement of an objective

lens system according to a fourth example of the

embodiment;

[0054]   Fig. 35 is a graph illustrating values of the

conditions (2) and (3) of the fourth example;

[0055]   Fig. 36 is a graph showing the spherical

aberration and the sine condition of the objective lens of

the fourth example;

[0056]   Fig. 37 is a graph showing astigmatism of the

objective lens of the fourth example;

[0057]   Figs. 38A-38D are graphs showing transverse

aberrations of the objective lens of the fourth example;

[0058]   Figs. 39A-39D are graphs showing the wavefront

aberrations of the objective lens of the fourth example;

[0059]   Fig. 40 is a graph showing a relationship between

an RMS value of the wavefront aberration and the field

angle of the fourth example;

[0060]   Fig. 41 is a graph showing the fsinW

characteristic of the objective lens of the fourth example;

[0061]   Fig. 42 shows a lens arrangement of an objective

lens system according to a fifth example of the embodiment;

[0062]   Fig. 43 is a graph illustrating values of the

conditions (2) and (3) of the fifth example;

[0063]   Fig. 44 is a graph showing the spherical

aberration and the sine condition of the objective lens of

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the fifth example;

[0064]   Fig. 45 is a graph showing astigmatism of the objective lens of the fifth example;

[0065]   Figs. 46A-46D are graphs showing transverse aberrations of the objective lens of the fifth example;

[0066]   Figs. 47A-47D are graphs showing the wavefront aberrations of the objective lens of the fifth example;

[0067]   Fig. 48 is a graph showing a relationship between an RMS value of the wavefront aberration and the field angle of the fifth example; and

[0068]   Fig. 49 is a graph showing the fsinW characteristic of the objective lens of the fifth example.

Detailed Description of the Embodiments

[0069]   Hereinafter, an embodiment according to the invention is described with reference to the accompanying drawings.

[0070]   Fig. 1 shows an objective optical system 10 having an objective lens L1 according to the embodiment of the invention. The objective lens L1 is specifically targeted for an optical recording/reproducing device for hologram recording media. The objective lens L1 is mounted on an actuator provided in the optical recording/reproducing device for hologram recording media.

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On Fig. 1 (and Figs. 26, 34 and 42), the left side is a light source side, and the right side is a recording medium side.

[0071]   The objective lens L1 has an incident surface r3 from which a beam from a light source enters and an exit surface from which a beam reflected from the recording medium enters. The incident surface r3 and the exit surface r4 are configured as rotationally symmetrical aspherical surfaces having shapes equal to each other and having the same radius of curvature. That is, the incident surface r3 and the exit surface r4 are symmetrical with respect to a plane perpendicular to an optical axis of the objective lens L1.

[0072]   An image height y of an image formed by the objective lens L1 is defined by the following equation (5):

$$y = f\sin W \qquad \cdots (5)$$

where f represents a focal length of the objective lens L1 and W represents a field angle. The objective lens L1 substantially satisfies a sine condition with regard to both collimated beams entering from the incident surface r3 and entering from the exit surface r4. With regard to the objective lens L1, an entrance pupil plane coincides with a front focal point and an exit pupil plane coincides with an image point. Accordingly, the objective lens L1 functions as a fourier transform lens.

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[0073] A rotationally symmetrical aspherical surface is expressed by a formula (1) below:

$$F(h) = \frac{h^2/r}{1 + \sqrt{1 - (1+k)\left(1/r\right)^2 h^2}} + A_4 h^4 + A_6 h^6 + A_8 h^8 + A_{10} h^{10} \quad \cdots (1)$$

where F(h) is a sag amount (i.e., a distance from a plane, which is tangential to the aspherical surface at the optical axis, to the aspherical surface at a position whose height with respect to the optical axis is h), r is a radius of curvature of the aspherical surface at the optical axis , k is a conical coefficient, and A_4-A_{10} are fourth, sixth, eighth, and tenth order aspherical coefficients, respectively. The formula (1) may include more than tenth order coefficients.

[0074] Each of the surfaces r3 and r4 of the objective lens L1 expressed by the formula (1) satisfies both of the following conditions (2) and (3).

$$-0.35 \leq dF(h)/dh \leq +0.35 \quad \cdots (2)$$

$$+0.3 \leq d^2F(h)/d^2h \leq +1.3 \quad \cdots (3)$$

[0075] The condition (2) defines a range of a first derivative of the sag amount F(h) with respect to h. That is, the condition (2) defines a shape of the surface r3 (r4) with regard to an inclination of the surface r3 (r4). The condition (3) defines a range of a second derivative of the sag amount F(h) with respect to h. That is, the

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condition (3) defines rate of change of the inclination of the surface r3 (r4).

[0076] If one or more of the conditions (2) and (3) are not satisfied, wavefront aberration deteriorates. More specifically, if $dF(h)/dh$ gets less than the lower limit of the condition (2) or if $d^2F(h)/d^2h$ gets less than the lower limit of the condition (3), a shortage of correction for spherical aberration or the sine condition is caused. Further, in such a case, on-axis or off-axis wavefront aberration deteriorates, and therefore the wavefront aberration exceeds Marechal criterion (0.07 λrms) used as a measure for determining whether recording/reproducing operation can be performed properly.

[0077] If $dF(h)/dh$ exceeds the upper limit of the condition (2) or if $d^2F(h)/d^2h$ exceeds the upper limit of the condition (3), correction of the sine condition becomes excessive. Further, in such a case, off-axis wavefront aberration deteriorates, and predetermined linearity of an fsinW characteristic used as a measure for an evaluation of optical performance of the fourier transform lens can not be satisfied because of excess and deficiency of correction of the sine condition.

[0078] In addition to the satisfaction of the conditions (2) and (3), the objective lens L1 satisfies a condition (4):

$$0.9 \leq r/tc \leq 1.5 \qquad \cdots (4)$$

where r represents the radius of curvature on the optical axis, tc represents a central lens thickness of the objective lens L1.

[0079]   If r/tc gets less than the lower limit of the condition (4) or if r/tc exceeds the upper limit of the condition (4), convergence of a off-axis meridional ray is deteriorated, and therefore astigmatism is caused. When astigmatism is caused, the wavefront aberration of the whole objective lens L1 considerably deteriorates. Further, in such a case, a range of the field angle within which the wavefront aberration becomes lower than or equal to Marechal criterion narrows with regard to both of the beam entering from the incident surface r3 and the beam entering from the exit surface r4. Further, in such a case, image transmissibility or image reproducibility used as a measure of lens performance of the fourier transform lens deteriorates.

[0080]   By satisfying the above mentioned conditions (2), (3) and (4), even though the objective lens L1 is configured as a single lens, the objective lens L1 not only has high lens performance (i.e., has sufficiently reduced aberrations) but also has the function as the fourier transform lens.

[0081]   Further, the objective lens L1 keeps high lens

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performance at high NA (numerical aperture) by properly

selecting its refractive index. Preferably, if the NA is

larger than or equal to 0.2, the refractive index is

greater than or equal to 1.6. When the refractive index

gets lower than 1.6, the shortage of correction of the

spherical aberration and the sine condition is caused. In

particular, a peripheral region (a region through which

rays having high height pass) of the objective lens L1

falls short of the refractive power, and therefore a

predetermined sine condition required for the fourier

transform lens cannot be satisfied. Further, the RMS value

of the wavefront aberration exceeds Marechal criterion

within the whole range of the maximum field angle.

[0082]   Recently, fine SLMs (Spatial Light Modulator)

having pixel pitches of 10-20 μm used for

recording/reproducing large amounts of information are in

practical use. To use the SLM with the objective lens L1 to

record/reproduce large amounts of information, the range of

the field angle of the objective lens L1 is preferably

larger than or equal to a diffraction angle of the first

order diffracted light at the pixel pitches of the SLM. If

the objective lens L1 has such configuration, first order

diffracted light as well as zeroth order diffracted light

can be used to record/reproduce large amounts of

information, and thereby OTF (Optical transfer Function)

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for digital bit information is enhanced. Further, the
digital bit information of the SLM, DMD (Digital
Micromirror Device®) and the like can be transferred with
high resolution, and therefore reproducibility in
recording/reproducing information is enhanced.

[0083]   A diffraction angle is defined by $\arcsin(\lambda/p)$,
where λ represents a wavelength and p represents the pixel
pitch. For example, when the wavelength λ is 532 nm and the
pixel pitch p is 10 μm, the diffraction angle of the first
order diffracted light is about 3°. That is, in addition to
satisfying the above mentioned conditions, the objective
lens L1 is configured to have a half field angle larger
than or equal to 3° and to have the wavefront aberration
less than or equal to Marechal criterion within the maximum
field angle.

[0084]   Hereafter, five concrete numerical examples of
the objective lens according to the embodiment of the
present invention will be explained.

[0085]   FIRST EXAMPLE

[0086]   Fig. 1 shows a lens arrangement of the objective
lens system 10 according to a first example of the present
invention. As shown in Fig. 1, the objective lens system 10
includes an optical element G1 which is one of a cover
layer of the spatial light modulator (SLM) and a plate

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constituting a phase shifter such as a compensator, the
objective lens L1, and a plate G2 constituting a cover
layer of a hologram recording medium. As described above,
the surface r3 of the objective lens L1 is the incident
surface, and the surface r4 is the exit surface.

[0087]   TABLE 1, TBALE 2 and TABLE 3 indicate numerical
structure of the objective lens system 10.

[0088]   TABLE 1

Surface No.	r	d	N	ν	Nd
#1	∞	0.200	1.51900	64.1	1.51633
#2	∞	0.411			
#3	1.325	1.313	1.85898	32.3	1.85026
#4	-1.325	0.411			
#5	∞	0.200	1.51900	64.1	1.51633
#6	∞	--			

[0089]   TABLE 2

	#3	#4
k	0.0000E+00	0.0000E+00
A4	-0.12286E+00	0.12286E+00
A6	-0.13248E+00	0.13248E+00
A8	0.0000E+00	0.0000E+00
A10	0.0000E+00	0.0000E+00
A12	0.0000E+00	0.0000E+00

[0090]   TABLE 3

	#3	#4
FNO	1:1.2	1:7.1
f	1.00	1.00
W	4.0	25.5
NA	0.43	0.07

[0091]   In TABLE 1, #1-#6 denote surface numbers assigned

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to optical surfaces in the objective lens system 10 from the beam incident side, r denotes radius of curvature on the optical axis (values of "r" of surfaces #1-#6 listed in TABLE 1 respectively correspond to surfaces indicated by reference numbers r1-r6 in Fig. 1), d denotes a distance (unit: mm) between a surface and a next surface along the optical axis (values of "d" of surfaces #1-#5 listed in TABLE 1 respectively correspond to distances indicated by reference numbers d1-d5 in Fig. 1), n denotes a refractive index at the design wavelength, ν is an Abbe number for d-ray (wavelength 587.56 nm) and nd denotes a refractive index for the d-ray.

[0092]   In TABLE 1, #1 and #2 are a surface r1 and a surface r2 of the optical element G1, #3 and #4 are incident surface r3 and the exit surface r4 of the objective lens L1, and #5 and #6 are a surface r5 and a surface r6 of the plate G2.

[0093]   The conical coefficient and the aspherical coefficients defining the rotational symmetrical aspherical surfaces #3 and #4 of the objective lens L1 are indicated in TABLE 2.

[0094]   As shown in TABLE 1 and TABLE 2, the surfaces #3 and #4 are symmetrical with respect to a plane perpendicular to the optical axis of the objective lens L1. However, the field angle of the objective lens L1 for the

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beam entering from the incident surface (#3) and the field

angle for the beam entering from the exit surface (#4) are

different from each other. Further, a diameter of the

entrance pupil of the objective lens L1 for the beam

entering from the incident surface (#3) and a diameter of

the entrance pupil of the objective lens L1 for the beam

entering from the exit surface (#4) are different from each

other.

[0095]   In TABLE 3, F numbers (FNO), focal lengths, field

angles W, numerical apertures NA for a collimated beam

entering from the incident surface r3 (#3) and for a

collimated beam entering from the exit surface r4 (#4) are

indicated. As shown in TABLE 3, with regard to the

collimated beam entering from the incident surface r3 (#3)

(i.e., the collimated beam from the light source), the

objective lens L1 provides a larger NA (0.43), and thereby

the objective lens L1 enables to record/reproduce high

definition optical information. With regard to the beam

entering from the exit surface r4 (#4) (i.e., the beam

returning from the recording media), the objective lens L1

accomplishes a high field angle, and thereby the objective

lens L1 enables to reproduce hologram information from the

recording medium with high resolution and high contrast.

[0096]   As is well known, the recording medium having

high density address information which enables to randomly

access the recording media have been provided. Since the
objective lens L1 provides high numerical aperture for the
beam entering from the incident surface r3 (#3), the
objective lens L1 has sufficient optical performance for
resolving the high density address information.

[0097]   Fig. 2 is a graph illustrating values of the
conditions (2) and (3) which define the shape of the
surface r3 (r4) of the objective lens L1. In Fig. 2, a
horizontal axis represents a height h from the optical axis,
a vertical axis represents a value of each of the
conditions (2) and (3). The horizontal axis represents a
relative height when the maximum height is represented by 1.
In Fig. 2, a solid curved line which passes through small
triangles represents values of dF(h)/dh, a broken curved
line which passes through small crosses represents values
of $d^2F(h)/d^2h$.

[0098]   TABLE 4 shows numerical data of the formula (1)
and the conditions (2) and (3) of the first example. Since
the surface r3 (#3) and the surface r4 (#4) have the same
shape, both of surface r3 (#3) and the surface r4 (#4) take
numerical data indicated in TABLE 4.

[0099]   TBALE 4

Relative h	Surface #3 (#4)			
	h [mm]	formula (1) F(h)	Condition(2) dF(h)/dh	Condition(3) $d^2F(h)/d^2h$
1	0.474	8.806E-02	0.31183	0.39524

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0.9	0.4266	7.075E-02	0.29077	0.48968
0.8	0.3792	5.552E-02	0.26572	0.56400
0.7	0.3318	4.226E-02	0.23757	0.62145
0.6	0.2844	3.090E-02	0.20703	0.66500
0.5	0.237	2.138E-02	0.17470	0.69728
0.4	0.1896	1.364E-02	0.14107	0.72055
0.3	0.1422	7.654E-03	0.10651	0.73668
0.2	0.0948	3.396E-03	0.07132	0.74714
0.1	0.0474	8.483E-04	0.03575	0.75300
0	0	0	0	0.75488
-0.1	-0.0474	8.483E-04	-0.03575	0.75300
-0.2	-0.0948	3.396E-03	-0.07132	0.74714
-0.3	-0.1422	7.654E-03	-0.10651	0.73668
-0.4	-0.1896	1.364E-02	-0.14107	0.72055
-0.5	-0.237	2.138E-02	-0.17470	0.69728
-0.6	-0.2844	3.090E-02	-0.20703	0.66500
-0.7	-0.3318	4.226E-02	-0.23757	0.62145
-0.8	-0.3792	5.552E-02	-0.26572	0.56400
-0.9	-0.4266	7.075E-02	-0.29077	0.48968
-1	-0.474	8.806E-02	-0.31183	0.39524

[0100]   Optical performance of the objective lens L1 will be explained. Figs. 3-7 are graphs showing optical performance of the objective lens L1 with regard to the beam entering from the incident surface r3. Figs. 8-12 are graphs showing optical performance of the objective lens L1 with regard to the beam entering from the exit surface r4.

[0101]   Fig. 3 is a graph showing the spherical aberration and the sine condition of the objective lens L1 with regard to the beam entering from the incident surface r3. In Fig. 3 (and the following drawings showing spherical aberrations), a horizontal axis represents positions in a direction of the optical axis (unit: mm), a vertical axis represents a height h from the optical axis (unit: mm), a solid curved line SA represents the spherical aberration,

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and a curved broken line SC represents the sine condition.

[0102]   Fig. 4 is a graph showing astigmatism of the objective lens L1 with regard to the beam entering from the incident surface r3. In Fig. 4 (and the following drawings showing astigmatism), a horizontal axis represents positions in a direction of the optical axis (unit: mm), a vertical axis represents an angle of emergence (unit: degree), a solid curved line S represents a sagittal image surface, and a curved broken line M represents a meridional image surface.

[0103]   Figs. 5A-5D are graphs showing transverse aberrations of the objective lens L1 with regard to the beam entering from the incident surface r3. Figs. 6A-6D are graphs showing the wavefront aberrations of the objective lens L1 with regard to the beam entering from the incident surface r3. In Figs. 5A-5D (and in Figs. 6A-6D), aberrations with respect to the beam having wavelength of 532 nm at the image heights y of 0.00, 0.02, 0.05 and 0.07 (mm) are indicated, respectively. The image heights y of 0.02mm, 0.05mm and 0.07mm correspond to the field angles W [degree] of 1.3, 2.7 and 4.0, respectively. The field angle of 4.0 degree is the maximum field angle.

[0104]   Fig. 7 is a graph showing a relationship between an RMS value of the wavefront aberration and the field angle with regard to the beam entering from the incident

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surface r3. In Fig. 7 (and in the following drawings showing the same relationship), a horizontal axis represents the field angle, a vertical axis represents the RMS value of the wavefront aberration.

[0105]   Fig. 8 is a graph showing the spherical aberration and the sine condition of the objective lens L1 with regard to the beam entering from the exit surface r4. Fig. 9 is a graph showing astigmatism of the objective lens L1 with regard to the beam entering from the exit surface r4.

[0106]   Figs. 10A-10D are graphs showing transverse aberrations of the objective lens L1 with regard to the beam entering from the exit surface r4. Figs. 11A-11D are graphs showing the wavefront aberrations of the objective lens L1 with regard to the beam entering from the exit surface r4. In Figs. 10A-10D (and in Figs. 11A-11D), aberrations with respect to the beam having wavelength of 532 nm at the image heights y of 0.00, 0.15, 0.29 and 0.43 (mm) are indicated, respectively. The image heights y of 0.15mm, 0.29mm and 0.43mm correspond to the field angles W [degree] of 8.5, 17.0 and 25.5, respectively. The field angle of 25.5 degree is the maximum field angle.

[0107]   Fig. 12 is a graph showing a relationship between an RMS value of the wavefront aberration and the field angle with regard to the beam entering from the exit

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surface r4.

[0108]   Fig. 13 is a graph showing the fsinW characteristic of the objective lens L1 defined by:

{(y'-y)/y} × 100 %

where y represents an ideal image height and y' represents an actual image height. That is, the fsinW characteristic represents the degree of satisfaction of the actual image height y' with respect to the ideal image height y. It should be noted that when the actual image height is equal to the ideal image height y, the fsinW characteristic takes a value of 0 %.

[0109]   In Fig. 13 (and in Figs. 25, 33, 41 and 49), a horizontal axis represents the fsinW characteristic, and a vertical axis represents a relative field angle. In Fig. 13, a solid curved line represents the fdinW characteristic with regard to the beam entering from the incident surface r3, and a broken curved line represents the fdinW characteristic with regard to the beam entering from the exit surface r4.

[0110]   As can be seen from Fig. 2 and TABLE 4, the objective lens L1 satisfies the conditions (2) and (3). Further, the objective lens L1 takes r/tc of 1.009, and therefore the objective lens L1 satisfies the condition (4). As can be seen from Figs. 3-6D and Figs. 8-11D, the aberrations are sufficiently corrected.

[0111]   As can be seen from Figs. 7 and 12, the RMS value
of the wavefront aberration is suppressed lower than or
equal to Marechal criterion within the maximum field angle
with regard to both of the beams entering from the surfaces
r3 and entering from the surface r4.

[0112]   As can be seen from Fig. 13, the fsinW
characteristic of the objective lens L1 used as a measure
for an evaluation of optical performance of the fourier
transform lens is excellent.

[0113]   As described above, although the objective lens
L1 is configured as a single lens, the objective lens L1
has sufficiently corrected aberrations and has high
performance as the fourier transform lens. Accordingly, the
objective lens L1 is suitable for recording/reproducing
information to/from the hologram disc.

[0114]   Further, as shown in TABLE 1 and TABLE 3, the
objective lens L1 has a sufficient refractive index for
supporting high NA. That is, the objective lens L1 achieves
the high NA while keeping the above mentioned high optical
performance.

[0115]   SECOND EXAMPLE

[0116]   A second example according to the embodiment will
be described. A lens arrangement of an objective lens
system according to the second example is substantially the

same as the first example, therefore, a detailed

explanation thereof are not repeated. The objective lens

system of the second example has an objective lens L2 in

place of the objective lens L1 of the first example.

[0117]   TABLE 5, TABLE 6 and TABLE 7 indicate numerical

structure of the objective lens system of the second

example. Symbols and fields in TABLEs 5-7 have the same

meanings as those indicated in TABLEs 1-3.

[0118]   TABLE 5

Surface No.	r	d	n	ν	Nd
#1	∞	0.200	1.51900	64.1	1.51633
#2	∞	0.438			
#3	1.157	1.173	1.73675	40.5	1.73077
#4	-1.157	0.438			
#5	∞	0.200	1.51900	64.1	1.51633
#6	∞	--			

[0119]   TABLE 6

	#3	#4
k	0.0000E+00	0.0000E+00
A4	-0.17636E+00	0.17636E+00
A6	-0.15177E+00	0.15177E+00
A8	0.0000E+00	0.0000E+00
A10	0.0000E+00	0.0000E+00
A12	0.0000E+00	0.0000E+00

[0120]   TABLE 7

	#3	#4
FNO	1:1.3	1:7.1
f	1.00	1.00
W	4.0	23.6
NA	0.400	0.075

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[0121]   Similarly to the objective lens L1 of the first

example, the surfaces #3 and #4 of the objective lens L2 of

the second example are symmetrical with respect to a plane

perpendicular to an optical axis of the objective lens L2.

The field angles of the objective lens L2 for the beam

entering from the incident surface r3 (#3) and for the beam

entering from the exit surface r4 (#4) are different from

each other. Further, diameters of the entrance pupils of

the objective lens L2 for the beam entering from the

incident surface (#3) and for the beam entering from the

exit surface (#4) are different from each other.

[0122]   As shown in TABLE 7, the objective lens L2

accomplishes a high NA for a collimated beam entering from

the incident surface, and therefore the objective lens L2

enables to record/reproduce high definition optical

information. Accordingly, by using the objective lens L2,

the high density address information in the recording media

can be read. Further, the objective lens L2 achieves a wide

field angle, and therefore the objective lens L2 enables to

detect the hologram information from the hologram disc with

high accuracy.

[0123]   Fig. 14 is a graph illustrating values of the

condition (2) and (3) which define the shape of the surface

r3 (r4) of the objective lens L2. TABLE 8 shows numerical

data of the formula (1) and the conditions (2) and (3)

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regarding the second example. Since the surface r3 (#3) and

the surface r4 (#4) have the same shape, both of the

surface r3 (#3) and the surface r4 (#4) take numerical data

indicated in TABLE 8.

[0124]   TBALE 8

Relative h	Surface #3 (#4)			
	h [mm]	formula (1) F(h)	Condition(2) dF(h)/dh	Condition(3) $d^2F(h)/d^2h$
1	0.446	8.983E-02	0.33927	0.49958
0.9	0.4014	7.208E-02	0.31493	0.58892
0.8	0.3568	5.650E-02	0.28699	0.66128
0.7	0.3122	4.297E-02	0.25616	0.71893
0.6	0.2676	3.140E-02	0.22304	0.76405
0.5	0.223	2.171E-02	0.18816	0.79862
0.4	0.1784	1.384E-02	0.15194	0.82440
0.3	0.1338	7.765E-03	0.11473	0.84288
0.2	0.0892	3.445E-03	0.07684	0.85522
0.1	0.0446	8.602E-04	0.03853	0.86228
0	0	0	0	0.86457
-0.1	-0.0446	8.602E-04	-0.03853	0.86228
-0.2	-0.0892	3.445E-03	-0.07684	0.85522
-0.3	-0.1338	7.765E-03	-0.11473	0.84288
-0.4	-0.1784	1.384E-02	-0.15194	0.82440
-0.5	-0.223	2.171E-02	-0.18816	0.79862
-0.6	-0.2676	3.140E-02	-0.22304	0.76405
-0.7	-0.3122	4.297E-02	-0.25616	0.71893
-0.8	-0.3568	5.650E-02	-0.28699	0.66128
-0.9	-0.4014	7.208E-02	-0.31493	0.58892
-1	-0.446	8.983E-02	-0.33927	0.49958

[0125]   Figs. 15-19 are graphs showing optical

performance of the objective lens L2 with regard to the

beam entering from the incident surface r3. Figs. 20-24 are

graphs showing optical performance of the objective lens L2

with regard to the beam entering from the exit surface r4.

[0126]   Each of Figs. 15 and 20 is a graph showing the

spherical aberration and the sine condition of the

objective lens L2. Each of Figs. 16 and 21 is a graph

showing astigmatism of the objective lens L2.

[0127]   Figs. 17A-17D are graphs showing transverse

aberrations of the objective lens L2 with regard to the

beam entering from the incident surface r3. Figs. 22A-22D

are graphs showing transverse aberrations of the objective

lens L2 with regard to the beam entering from the exit

surface r4.

[0128]   Figs. 18A-18D are graphs showing the wavefront

aberrations of the objective lens L2 with regard to the

beam entering from the incident surface r3. Similarly, Figs.

23A-23D are graphs showing the wavefront aberrations of the

objective lens L2 with regard to the beam entering from the

exit surface r4.

[0129]   In Figs. 17A-17D (and in Figs. 18A-18D),

aberrations with respect to the beam having wavelength of

532 nm at the image heights y of 0.00, 0.02, 0.05 and 0.07

(mm) are indicated, respectively. The image heights y of

0.02mm, 0.05mm and 0.07mm correspond to the field angles W

[degree] of 1.3, 2.7 and 4.0, respectively. The field angle

of 4.0 degree is the maximum field angle.

[0130]   In Figs. 22A-22D (and in Figs. 23A-23D),

aberrations with respect to the beam having wavelength of

532 nm at the image heights y of 0.00, 0.14, 0.27 and 0.40

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(mm) are indicated, respectively. The image heights y of

0.14mm, 0.27mm and 0.40mm correspond to the field angles W

[degree] of 7.9, 15.7 and 23.6, respectively. The field

angle of 23.6 degree is the maximum field angle.

[0131]   Fig. 19 is a graph showing a relationship between

an RMS value of the wavefront aberration and the field

angle with regard to the beam entering from the incident

surface r3. Fig. 24 is a graph showing a relationship

between an RMS value of the wavefront aberration and the

field angle with regard to the beam entering from the exit

surface r4.

[0132]   Similarly to Fig. 13, Fig. 25 is a graph showing

the fsinW characteristic of the objective lens L2. In Fig.

25, a solid curved line represents the fdinW characteristic

with regard to the beam entering from the incident surface

r3, and a broken curved line represents the fdinW

characteristic with regard to the beam entering from the

exit surface r4.

[0133]   As can be seen from Fig. 14 and TABLE 8, the

objective lens L2 of the second example satisfies the

conditions (2) and (3). Further, the objective lens L2

takes r/tc of 0.986, and therefore the objective lens L2

satisfies the condition (4). As can be seen from Figs. 15-

18D and Figs. 20-23D, the aberrations are sufficiently

corrected.

[0134]   As can be seen from Figs. 19 and 24, the RMS value of the wavefront aberration is suppressed lower than or equal to Marechal criterion within the maximum field angle with regard to both of the beams entering from the surfaces r3 and r4.

[0135]   As can be seen from Fig. 25, the fsinW characteristic of the objective lens L2 used as a measure for an evaluation of optical performance of the fourier transform lens is excellent.

[0136]   As described above, although the objective lens L2 is configured as a single lens, the objective lens L2 has sufficiently corrected aberrations and has high performance as the fourier transform lens. Accordingly, the objective lens L2 is suitable for recording/reproducing information to/from the hologram disc.

[0137]   Further, as shown in TABLE 5 and TABLE 7, the objective lens L2 has a sufficient refractive index for supporting high NA. That is, the objective lens L2 achieves the high NA while keeping the above mentioned high optical performance.

[0138]   THIRD EXAMPLE

[0139]   Fig. 26 shows a lens arrangement of an objective lens system 30 according to a third example of the embodiment of the present invention. As shown in Fig. 26,

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the objective lens system 30 includes an optical element G3

which is one of a cover layer of the spatial light

modulator (SLM) and a plate constituting a phase shifter

such as a compensator, an objective lens L3, and a plate G4

constituting a cover layer of the recording medium. The

optical element G3 is located on a light source side with

respect to the objective lens L3. As described above, the

surface r3 of the objective lens L3 is an incident surface,

and the surface r4 of the objective lens L3 is an exit

surface.

[0140]   TABLE 9 and TABLE 10 indicate numerical structure

of the objective lens system 30. Symbols and fields in

TABLEs 9 and 10 have the same meanings as those indicated

in TABLEs 1 and 2. Values of "r" of surfaces #1-#6 listed

in TABLE 9 respectively correspond to surfaces indicated by

reference numbers r1-r6 in Fig. 26. Values of "d" of

surfaces #1-#5 listed in TABLE 9 respectively correspond to

distances indicated by reference numbers d1-d5 in Fig. 26.

[0141]   TABLE 9

FNO=1:3.1, f=1.00, W=9.2, NA=0.16

Surface No.	r	d	n	ν	nd
#1	∞	0.200	1.51900	64.1	1.51633
#2	∞	0.520			
#3	0.979	0.915	1.59233	61.2	1.58913
#4	-0.979	0.520			
#5	∞	0.200	1.51900	64.1	1.51633
#6	∞	--			

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[0142]　　TABLE 10

	#3	#4
k	0.0000E+00	0.0000E+00
A4	-0.28725E+00	0.28725E+00
A6	-0.15607E+00	0.15607E+00
A8	0.0000E+00	0.0000E+00
A10	0.0000E+00	0.0000E+00
A12	0.0000E+00	0.0000E+00

[0143]　　In contrast to the objective lens L1 and the objective lens L2, the objective lens L3 is configured such that not only surfaces r3 (#3) and r4 (#4) of the objective lens L3 are symmetrical with respect to a plane perpendicular to an optical axis of the objective lens L3, but also the field angles for the beam entering from the incident surface r3 (#3) and for the beam entering from the exit surface r4 (#4) are equal to each other. Further, the entrance pupils for the beam entering from the incident surface r3 (#3) and for the beam entering from the exit surface r4 (#4) are equal to each other. As indicated in TABLE 9, the objective lens L3 has the F number (FNO) of 1:3.1, a focus length (f) of 1.00 mm, a field angle (W) of 9.2 degree, and the numerical aperture (NA) of 0.16 with regard to both of the beams entering from the surfaces r3 and entering from the surface r4.

[0144]　　As shown in TABLE 9, the objective lens L3 achieves a wide field angle, and therefore the objective lens L3 enables to detect the hologram information from the

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hologram disc with high accuracy.

[0145]   Fig. 27 is a graph illustrating values of the conditions (2) and (3) which define the shape of the surface r3 (r4) of the objective lens L3. TABLE 11 shows numerical data of the formula (1) and the conditions (2) and (3) regarding the third example. Since the surface r3 (#3) and the surface r4 (#4) have the same shape, both of the surfaces r3 and r4 take numerical data indicated in TABLE 11.

[0146]   TBALE 11

| Relative h | Surface #3 (#4) | | | |
	h [mm]	formula (1) F(h)	Condition(2) dF(h)/dh	Condition(3) d²F(h)/d²h
1	0.272	3.859E-02	0.26691	0.92577
0.9	0.2448	3.113E-02	0.24168	0.93069
0.8	0.2176	2.451E-02	0.21621	0.94295
0.7	0.1904	1.870E-02	0.19036	0.95795
0.6	0.1632	1.371E-02	0.16409	0.97340
0.5	0.136	9.497E-03	0.13742	0.98768
0.4	0.1088	6.067E-03	0.11038	0.99987
0.3	0.0816	3.408E-03	0.08305	1.00950
0.2	0.0544	1.513E-03	0.05549	1.01638
0.1	0.0272	3.781E-04	0.02778	1.02050
0	0	0	0	1.02187
-0.1	-0.0272	3.781E-04	-0.02778	1.02050
-0.2	-0.0544	1.513E-03	-0.05549	1.01638
-0.3	-0.0816	3.408E-03	-0.08305	1.00950
-0.4	-0.1088	6.067E-03	-0.11038	0.99987
-0.5	-0.136	9.497E-03	-0.13742	0.98768
-0.6	-0.1632	1.371E-02	-0.16409	0.97340
-0.7	-0.1904	1.870E-02	-0.19036	0.95795
-0.8	-0.2176	2.451E-02	-0.21621	0.94295
-0.9	-0.2448	3.113E-02	-0.24168	0.93096
-1	-0.272	3.859E-02	-0.26691	0.92577

[0147]　Fig. 28 is a graph showing the spherical aberration and the sine condition of the objective lens L3. Fig. 29 is a graph showing astigmatism of the objective lens L3.

[0148]　Figs. 30A-30D are graphs showing transverse aberrations of the objective lens L3. Figs. 31A-31D are graphs showing the wavefront aberrations of the objective lens L3. In Figs. 30A-30D (and in Figs. 31A-31D), aberrations with respect to the beam having wavelength of 532 nm at the image heights y of 0.00, 0.05, 0.11 and 0.16 (mm) are indicated, respectively. The image heights y of 0.05mm, 0.11mm and 0.16mm correspond to the field angles W [degree] of 3.1, 6.1 and 9.2, respectively. The field angle of 9.2 degree is the maximum field angle.

[0149]　Fig. 32 is a graph showing a relationship between an RMS value of the wavefront aberration and the field angle. Similarly to Fig. 13, Fig. 33 is a graph showing the fsinW characteristic of the objective lens L3.

[0150]　As can be seen from Fig. 27 and TABLE 11, the objective lens L3 of the third example satisfies the conditions (2) and (3). Further, the objective lens L3 takes r/tc of 1.069, and therefore the objective lens L3 satisfies the condition (4). As can be seen from Figs. 28-31D, the aberrations are sufficiently corrected.

[0151]　As can be seen from Fig. 32, the RMS value of the

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wavefront aberration is suppressed lower than or equal to Marechal criterion within the maximum field angle with regard to both of the beams entering from the surfaces r3 and r4.

[0152]   As can be seen from Fig. 33, the fsinW characteristic of the objective lens L3 used as a measure for an evaluation of optical performance of the fourier transform lens is excellent.

[0153]   As described above, although the objective lens L3 is configured as a single lens, the objective lens L3 has sufficiently corrected aberrations and has high performance as the fourier transform lens. Accordingly, the objective lens L3 is suitable for recording/reproducing information to/from the hologram disc.

[0154]   FOURTH EXAMPLE

[0155]   Fig. 34 shows a lens arrangement of an objective lens system 40 according to a fourth example of the embodiment of the present invention. As shown in Fig. 34, the objective lens system 40 includes an optical element G5 which is one of a cover layer of the spatial light modulator (SLM) and a plate constituting a phase shifter such as a compensator, an objective lens L4, and a plate G6 constituting a cover layer of the recording medium. The optical element G5 is located on a light source side with

respect to the objective lens L4. As described above, the surface r3 of the objective lens L4 is an incident surface, and the surface r4 of the objective lens L4 is an exit surface.

[0156]   TABLE 12 and TABLE 13 indicate numerical structure of the objective lens system 40. Symbols and fields in TABLEs 12 and 13 have the same meanings as those indicated in TABLEs 9 and 10. Values of "r" of surfaces #1-#6 listed in TABLE 12 respectively correspond to surfaces indicated by reference numbers r1-r6 in Fig. 34. Values of "d" of surfaces #1-#5 listed in TABLE 12 respectively correspond to distances indicated by reference numbers d1-d5 in Fig. 34.

[0157]   TABLE 12

FNO=1:3.3, f=1.00, W=8.6, NA=0.15

Surface No.	r	d	n	ν	nd
#1	∞	0.200	1.51900	64.1	1.51633
#2	∞	0.537			
#3	1.434	1.027	1.85898	32.3	1.85026
#4	-1.434	0.537			
#5	∞	0.200	1.51900	64.1	1.51633
#6	∞	--			

[0158]   TABLE 13

	#3	#4
k	0.0000E+00	0.0000E+00
A4	-0.18846E+00	0.18846E+00
A6	0.25466E+01	-0.25466E+01
A8	-0.23515E+02	0.23515E+02
A10	0.0000E+00	0.0000E+00
A12	0.0000E+00	0.0000E+00

[0159]　　Similarly to the objective lens L3, the objective lens L4 is configured such that not only surfaces r3 (#3) and r4 (#4) of the objective lens L3 are symmetrical with respect to a plane perpendicular to an optical axis of the objective lens L4, but also the field angles for the beam entering from the incident surface r3 and for the beam entering from the exit surface r4 are equal to each other. Further, the entrance pupils for the beam entering from the incident surface r3 (#3) and for the beam entering from the exit surface r4 (#4) are equal to each other. As indicated in TABLE 12, the objective lens L4 has the F number (FNO) of 1:3.3, a focus length (f) of 1.00 mm, a field angle (W) of 8.6 degree, and the numerical aperture (NA) of 0.15 with regard to both of the beams entering from the surfaces r3 and entering from the surface r4.

[0160]　　As shown in TABLE 12, the objective lens L4 achieves a wide field angle, and therefore the objective lens L4 enables to detect the hologram information from the hologram disc with high accuracy.

[0161]　　Fig. 35 is a graph illustrating values of the conditions (2) and (3) which define the shape of the surface r3 (r4) of the objective lens L4. TABLE 14 shows numerical data of the formula (1) and the conditions (2) and (3) regarding the fourth example. Since the surface r3

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(#3) and the surface r4 (#4) have the same shape, both of

the surfaces r3 and r4 take numerical data indicated in

TABLE 14.

[0162]   TBALE 14

Relative h	Surface #3 (#4)			
	h [mm]	formula (1) F(h)	Condition(2) dF(h)/dh	Condition(3) $d^2F(h)/d^2h$
1	0.255	2.287E-02	0.17155	0.54596
0.9	0.2295	1.849E-02	0.15649	0.62569
0.8	0.204	1.459E-02	0.14000	0.66259
0.7	0.1785	1.116E-02	0.12289	0.67702
0.6	0.153	8.188E-03	0.10555	0.68169
0.5	0.1275	5.681E-03	0.08814	0.68370
0.4	0.102	3.633E-03	0.07068	0.68616
0.3	0.0765	2.043E-03	0.05314	0.68968
0.2	0.051	9.075E-04	0.03550	0.69351
0.1	0.0255	2.268E-04	0.01778	0.69646
0	0	0	0	0.69757
-0.1	-0.0255	2.268E-04	-0.01778	0.69646
-0.2	-0.051	9.075E-04	-0.03550	0.69351
-0.3	-0.0765	2.043E-03	-0.05314	0.68968
-0.4	-0.102	3.633E-03	-0.07068	0.68616
-0.5	-0.1275	5.681E-03	-0.08814	0.68370
-0.6	-0.153	8.188E-03	-0.10555	0.68169
-0.7	-0.1785	1.116E-02	-0.12289	0.67702
-0.8	-0.204	1.459E-02	-0.14000	0.66259
-0.9	-0.2295	1.849E-02	-0.15649	0.62596
-1	-0.255	2.287E-02	-0.17155	0.54596

[0163]   Fig. 36 is a graph showing the spherical

aberration and the sine condition of the objective lens L4.

Fig. 37 is a graph showing astigmatism of the objective

lens L4.

[0164]   Figs. 38A-38D are graphs showing transverse

aberrations of the objective lens L4. Figs. 39A-39D are

graphs showing the wavefront aberrations of the objective

lens L4. In Figs. 38A-38D (and in Figs. 39A-39D),

aberrations with respect to the beam having wavelength of

532 nm at the image heights y of 0.00, 0.05, 0.10 and 0.15

(mm) are indicated, respectively. The image heights y of

0.05mm, 0.10mm and 0.15mm correspond to the field angles W

[degree] of 2.9, 5.8 and 8.6, respectively. The field angle

of 8.6 degree is the maximum field angle.

[0165]   Fig. 40 is a graph showing a relationship between

an RMS value of the wavefront aberration and the field

angle. Similarly to Fig. 13, Fig. 41 is a graph showing the

fsinW characteristic of the objective lens L4.

[0166]   As can be seen from Fig. 35 and TABLE 14, the

objective lens L4 of the fourth example satisfies the

conditions (2) and (3). Further, the objective lens L4

takes r/tc of 1.395, and therefore the objective lens L4

satisfies the condition (4). As can be seen from Figs. 36-

39D, the aberrations are sufficiently corrected.

[0167]   As can be seen from Fig. 40, the RMS value of the

wavefront aberration is suppressed lower than or equal to

Marechal criterion within the maximum field angle with

regard to both of the beams entering from the surfaces r3

and r4.

[0168]   As can be seen from Fig. 41, the fsinW

characteristic used as a measure for an evaluation of

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optical performance of the fourier transform lens is excellent.

[0169]   As described above, although the objective lens L4 is configured as a single lens, the objective lens L4 has sufficiently corrected aberrations and has high performance as the fourier transform lens. Accordingly, the objective lens L4 is suitable for recording/reproducing information to/from the hologram disc.

[0170]   FIFTH EXAMPLE

[0171]   Fig. 42 shows a lens arrangement of an objective lens system 50 according to a fifth example of the embodiment of the present invention. As shown in Fig. 42, the objective lens system 50 includes an optical element G7 which is one of a cover layer of the spatial light modulator (SLM) and a plate constituting a phase shifter such as a compensator, an objective lens L5, and a plate G8 constituting a cover layer of the recording medium. The optical element G7 is located on a light source side with respect to the objective lens L5. As described above, the surface r3 of the objective lens L5 is an incident surface, and the surface r4 of the objective lens L5 is an exit surface.

[0172]   TABLE 15 and TABLE 16 indicate numerical structure of the objective lens system 50. Symbols and

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fields in TABLEs 15 and 16 have the same meanings as those indicated in TABLEs 9 and 10. Values of "r" of surfaces #1-#6 listed in TABLE 15 respectively correspond to surfaces indicated by reference numbers r1-r6 in Fig. 42. Values of "d" of surfaces #1-#5 listed in TABLE 15 respectively correspond to distances indicated by reference numbers d1-d5 in Fig 42.

[0173]   TABLE 15

FNO=1:3.3, f=1.00, W=8.6, NA=0.15

Surface No.	r	d	n	ν	nd
#1	∞	0.200	1.51900	64.1	1.51633
#2	∞	0.647			
#3	0.775	0.565	1.43578	95.0	1.43425
#4	-0.775	0.647			
#5	∞	0.200	1.51900	64.1	1.51633
#6	∞	--			

[0174]   TABLE 16

	#3	#4
K	0.0000E+00	0.0000E+00
A4	-0.63142E+00	0.63142E+00
A6	0.39139E+01	-0.39139E+01
A8	-0.32962E+02	0.32962E+02
A10	0.0000E+00	0.0000E+00
A12	0.0000E+00	0.0000E+00

[0175]   Similarly to the objective lenses L3 and L4, the objective lens L5 is configured such that not only surfaces r3 (#3) and r4 (#4) are symmetrical with respect to a plane perpendicular to an optical axis of the objective lens L5,

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but also the field angles for the beam entering from the incident surface r3 and for the beam entering from the exit surface r4 are equal to each other. Further, the entrance pupils for the beam entering from the incident surface r3 (#3) and for the beam entering from the exit surface r4 (#4) are equal to each other. As indicated in TABLE 15, the objective lens L5 has the F number (FNO) of 1:3.3, a focus length (f) of 1.00 mm, a field angle (W) of 8.6 degree, and the numerical aperture (NA) of 0.15 with regard to both of the beam entering from the surfaces r3 and the beam entering from the surface r4.

[0176] As shown in TABLE 15, the objective lens L5 achieves a wide field angle, and therefore the objective lens L5 enables to detect the hologram information from the hologram disc with high accuracy.

[0177] Fig. 43 is a graph illustrating values of the conditions (2) and (3) which define the shape of the surface r3 (r4) of the objective lens L5. TABLE 17 shows numerical data of the formula (1) and the conditions (2) and (3) regarding the fifth example. Since the surface r3 (#3) and the surface r4 (#4) have the same shape, both of the surfaces r3 and r4 take numerical data indicated in TABLE 17.

[0178] TBALE 17

Relative h	Surface #3 (#4)			
	h [mm]	formula (1) F(h)	Condition(2) dF(h)/dh	Condition(3) $d^2F(h)/d^2h$
1	0.276	5.088E-02	0.33339	0.86932
0.9	0.2484	4.092E-02	0.30642	1.06374
0.8	0.2208	3.213E-02	0.27556	1.16055
0.7	0.1932	2.447E-02	0.24284	1.20521
0.6	0.1656	1.790E-02	0.20925	1.22624
0.5	0.138	1.238E-02	0.17522	1.23954
0.4	0.1104	7.903E-03	0.14083	1.25217
0.3	0.0828	4.435E-03	0.10609	1.26552
0.2	0.0552	1.968E-03	0.07098	1.27797
0.1	0.0276	4.915E-04	0.03558	1.28689
0	0	0	0	1.29014
-0.1	-0.0276	4.915E-04	-0.03558	1.28689
-0.2	-0.0552	1.968E-03	-0.07098	1.27797
-0.3	-0.0828	4.435E-03	-0.10609	1.26552
-0.4	-0.1104	7.903E-03	-0.14083	1.25217
-0.5	-0.138	1.238E-02	-0.17522	1.23954
-0.6	-0.1656	1.790E-02	-0.20925	1.22624
-0.7	-0.1932	2.447E-02	-0.24284	1.20521
-0.8	-0.2208	3.213E-02	-0.27556	1.16055
-0.9	-0.2484	4.092E-02	-0.30642	1.06374
-1	-0.276	5.008E-02	-0.33339	0.86932

[0179] Fig. 44 is a graph showing the spherical aberration and the sine condition of the objective lens L5. Fig. 45 is a graph showing astigmatism of the objective lens L5.

[0180] Figs. 46A-46D are graphs showing transverse aberrations of the objective lens L5. Figs. 47A-47D are graphs showing the wavefront aberrations of the objective lens L5. In Figs. 46A-46D (and in Figs. 47A-47D), aberrations with respect to the beam having wavelength of 532 nm at the image heights y of 0.00, 0.05, 0.10 and 0.15 (mm) are indicated, respectively. The image heights y of

0.05mm, 0.10mm and 0.15mm correspond to the field angles W

[degree] of 2.9, 5.8 and 8.6, respectively. The field angle

of 8.6 degree is the maximum field angle.

[0181]   Fig. 48 is a graph showing a relationship between

an RMS value of the wavefront aberration and the field

angle. Similarly to Fig. 13, Fig. 49 is a graph showing the

fsinW characteristic of the objective lens L5.

[0182]   As can be seen from Fig. 43 and TABLE 17, the

objective lens L5 of the fifth example satisfies the

conditions (2) and (3). Further, the objective lens L5

takes r/tc of 1.371, and therefore the objective lens L5

satisfies the condition (4). As can be seen from Figs. 44-

47D, the aberrations are sufficiently corrected.

[0183]   As can be seen from Fig. 48, the RMS value of the

wavefront aberration is suppressed lower than or equal to

Marechal criterion within the maximum field angle with

regard to both of the beams entering from the surfaces r3

and r4.

[0184]   As can be seen from Fig. 49, the fsinW

characteristic used as a measure for an evaluation of

optical performance of the fourier transform lens is

excellent.

[0185]   As described above, although the objective lens

L5 is configured as a single lens, the objective lens L5

has sufficiently corrected aberrations and has high

performance as the fourier transform lens. Accordingly, the objective lens L5 is suitable for recording/reproducing information to/from the hologram disc.

[0186]   As described above, according to the embodiment of the present invention, an objective lens which consists of a single lens having sufficiently suppressed aberrations and which has the function of the fourier transform lens is provided.

[0187]   Since the objective lens according to the invention is configured to be a single lens, structures and techniques adopted in the conventional optical recording/reproducing apparatus using a single element objective lens can be utilized to configure the optical recording/reproducing device for hologram disc.

[0188]   In particular, the objective lens according to the invention can relatively easily be mounted on the conventional optical pick-up adopted in the conventional optical recording/reproducing apparatus. Therefore, cost and time required for development and manufacture of the optical recording/reproducing device for hologram disc can be reduced.

[0189]   Further, the incident and exit surfaces of the objective lens according to the embodiment of the invention have the same shape. Therefore, the objective lens according to the invention has the following advantageous.

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Cost of a mold of the objective lens can be reduced. The
objective lens can be mounted on the optical
recording/reproducing device during manufacturing process
with disregard to orientation of the objective lens. There
is no necessity of adjustment with regard to decentering of
lenses constituting an objective lens in contrast to the
conventional fourier transform lens consisting of a
plurality of lenses disclosed in the above mentioned
publication HEI11-133297. By arranging two or more
objective lenses according to the invention so that the
objective lenses are opposed to each other, a various types
of relay lens systems having various magnifications can be
accomplished.

[0190]   Although the present invention has been described
in considerable detail with reference to certain preferred
embodiments thereof, other embodiments are possible.

[0191]   The present disclosure relates to the subject
matter contained in Japanese Patent Application No. P2002-
346730, filed on November 29, 2002, which is expressly
incorporated herein by reference in its entirety.